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BLUETOOTH TECHNOLOGY AND ITS IMPLEMENTATION IN SENSING DEVICES

by

Ali M Aljuaied

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Thesis Advisor:	Xiaoping Yun
Second Reader:	Wolfgang Baer

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Bluetooth Wireless technology is the world's new short range RF transmission standard for small form factor, low cost, and short-range radio link between portable and desktop devices. This technology does not replace Wireless LANs rather it compliments them. Bluetooth wireless technology has many advantages over other Wireless LAN technologies, which makes it attractive to many applications.

One such application is in the area of sensors and gauges on-board ships and submarines. If these are connected wirelessly, a huge amount of cables are eliminated and more user mobility is gained.

This thesis studies the theories and principles of Bluetooth technology and discusses the approaches of connecting Bluetooth to sensors and gauges. Some of the Bluetooth products available in the market were acquired for testing and evaluation.

In the course of the study, it was found that the technology was not mainly developed with sensor and gauge applications in mind. However, integrating sensors with Bluetooth modules can be achieved by one of two approaches. One approach requires an expensive Development Kit and is limited to manufacturers integrating Bluetooth technology into their sensor products in compliance with Bluetooth Specifications. The other inexpensive approach requires custom circuit designing and program coding and is preferred by university researchers.

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BLUETOOTH TECHNOLOGY AND ITS IMPLEMENTATION IN SENSING DEVICES

Ali M. Aljuaied
Lieutenant Commander, Royal Saudi Naval Forces
B.S., Pakistan Naval Academy, 1988

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Author: ______________________
Ali M. Aljuaied

Approved by: ______________________
Xiaoping Yun, Thesis Advisor

____
Wolfgang Baer, Second Reader

____
Dan Boger, Chairman
Information Warfare Academic Group

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ABSTRACT

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I. INTRODUCTION

The world is going wireless. The prohibitive costs of building wired network infrastructures have paved the way for wireless networking on a global scale. Customers today are offered with a wide variety of wireless technologies, systems, and venders to address needs for wireless data collection. However, most customers find that no single wireless solution is suitable for all applications. Mobile and spontaneous networks are becoming more and more important these days as wireless and mobile devices become cheaper and are more usable in every day life.

The latest technology in Wireless LAN called Bluetooth is a de facto standard for very low-powered and short-range radio connection linking all portable devices having Bluetooth technology. The Bluetooth technology was developed to provide a wireless interconnect between small mobile devices and their peripherals. Target markets for this technology include the mobile computer, the mobile phone, small personal digital assistants and peripherals.

The goals of the technology did not include developing another Wireless LAN, which already exists in markets in many new developments. Whereas Wireless LANs are designed to efficiently connect large groups of people over a common backbone, the Bluetooth technology was designed to connect mobile devices over a personal and private connection. The Bluetooth technology tries to emulate the cost, security, and capabilities of common cables carried by mobile travelers. The technology must be

- Secured as a cable.
- Manufactured for about the same cost as a cable;
- Connected to a variety of devices available to the mobile user and support data rates that are consistent with a mobile traveler's needs;
- Designed to support many simultaneous and private connections;
- Designed to support voice and data simultaneously.

- Powered with low power and compacted in small size to support small portable devices.
- Operated globally as mobile devices travel and must work with devices founded in other parts of the world.

Current portable devices use infrared links (IrDA) to communicate with each other. Although infrared transceivers are inexpensive, they have a limited range (3-6 feet), require direct line-of-sight, are sensitive to direction, and can, in a principle, only be used between two devices. In contrast, Bluetooth uses RF radio that has much greater range, can propagate around objects and through various materials, and connect to many devices simultaneously. In addition, radio interfaces do not require user interaction.

The Bluetooth technology serves normal users but can be used in military applications too. Sensors and gauges are very important to military applications and are found in most military equipment. They measure different type of quantities such as temperature, pressure and vibration. They are wired to monitor stations. By using Bluetooth modules connected to sensors and gauges many advantages are gained.

A. BLUETOOTH USAGE MODELS

While the Bluetooth usage model is based on connecting devices together, it additionally focuses on three broad categories: voice/data access points, peripheral interconnects, and Personal Area Networking (PAN).

1. Voice/Data Access Points

Voice/data access points are one of the key initial usage models and involve connecting a computing device to a communicating device via a secure wireless link. For example, a mobile computer equipped with Bluetooth technology could link to a mobile phone that uses Bluetooth technology to access the Internet for e-mail. The mobile phone acts as a personal access point. Even more ideal, the notebook can connect to the Internet via the cell phone carried in a briefcase or purse. The Bluetooth usage model also envisions public data access points in the future: current data equipped pay phones in airports being upgraded with Bluetooth modems. This would allow any mobile device equipped with Bluetooth technology to easily connect to the Internet while located within ten meters of that access point. These access points could, of course, support much higher data rates than today's modems. These public spaces could connect a variety of private Bluetooth access points via a LAN routed to the Internet over a DSL line, allowing each access point a private 1Mbps connection to the Internet.

2. Peripheral Interconnects

The second category of uses, peripheral interconnects, involves connecting other devices together, such as standard keyboards, mice, and joysticks that work over a wireless link. The Bluetooth link is built into the mobile computer; therefore, the cost of the peripheral device is less because an access point is not needed. Additionally, many of these devices can be used in multiple markets. For example, a Bluetooth headset used in the office could be connected to a Bluetooth access point provides access to the office phone and multi-media functions of the mobile computer.

When mobile, the same headset could be used to interface with the cellular phone (which can now remain in a briefcase or purse). Another aspect of a short-range link like Bluetooth is in the area of proximity security devices. In this case, if one device is not within range of another device, the first device will go into a high security mode.

3. Personal Area Networking

The last usage model, Personal Area Networking (PAN), focuses on the ad-hoc formation and breakdown of personal networks. A possible scenario for this model would be meeting someone in an airport and quickly and securely exchanging documents by establishing a private piconet. In the future, Bluetooth kiosks could provide access to electronic media that could be quickly downloaded for later access on the mobile device.

B. GOAL FOR THIS THESIS

The goal of this thesis is to analyze the Bluetooth technology and to test some of the available products in the market and to evaluate its applicability for the existing project of connecting wireless sensors and gauges.

C. THESIS OUTLINE

This thesis is organized in the following sequence. Chapter II gives an overall overview of the Wireless LANs technologies. Chapter III discusses Bluetooth technology from the point of view of protocols and topology. Chapter IV compares Bluetooth to

Wireless LANs IEEE 802.11. Chapter V discusses integrating Bluetooth with sensors. Chapter VI discusses some of Bluetooth products brought to laboratory for testing. Chapter VII concludes with recommendations.

II. WIRELESS LAN OVERVIEW

This chapter gives an overview of the Wireless LAN generations and the technologies used in Wireless LAN, and a summary of the different standards used in Wireless LAN.

A. INTRODUCTION AND BACKGROUND

A Wireless LAN is a flexible data communication system implemented as an extension to, or as an alternative for, a wired LAN within a building or campus. Using electromagnetic waves, Wireless LANs transmit and receive data over the air, minimizing the need for wired connections. Thus, Wireless LANs combine data connectivity with user mobility, and, through a simplified configuration, enable movable LANs.

Over the last seven years, Wireless LANs have gained strong popularity in a number of applications, including health-care, retail, manufacturing, warehousing, and academic arenas. These industries have profited from the productivity gains of using hand-held terminals and notebook computers to transmit real-time information to centralized hosts for processing. Today Wireless LANs are becoming more widely recognized as a general-purpose connectivity alternative for a broad range of applications.

Since The development of Wireless LAN its applications have gradually gone through many generations; the first generation, which operated in the unlicensed 902-928MHz ISM band had limited range and throughput, but proved useful in many warehouse applications. These systems evolved from advances in semiconductors technology. Unfortunately many products operating in that band were developed, and the band quickly became over crowded with a variety of unlicensed products. Building upon technology originally developed for military applications, spread spectrum techniques were employed to minimize sensitivity to interference. This approach allowed the design of 900MHz Wireless LAN products having nominal data rates of 500Kb/s. Ultimately, the growing popularity of the band for a large range of unlicensed products, aggravated by the limited bandwidth, caused users of Wireless LAN to look to a different frequency band for growth in performance. See Figure 1.

The second generation of Wireless LAN evolved in the 2.40-2.483GHz ISM bands, which was also enabled by semiconductor advances. Because a major user of 2.4GHz ISM band is microwave ovens, a transmission scheme less sensitive to this type of noise source needs to be used. Extending the experience from the crowded 900MHZ band, spread spectrum techniques combined with more available bandwidth and more complex modulation schemes allowed this generation to operate at data rates of up to 2.0Mb/s.

The third generation of Wireless LAN products is presently evolving to more complex modulation formats in the 2.4GHz band to allow nominal 11Mb/s raw data rates and approximately 7Mb/s throughput.

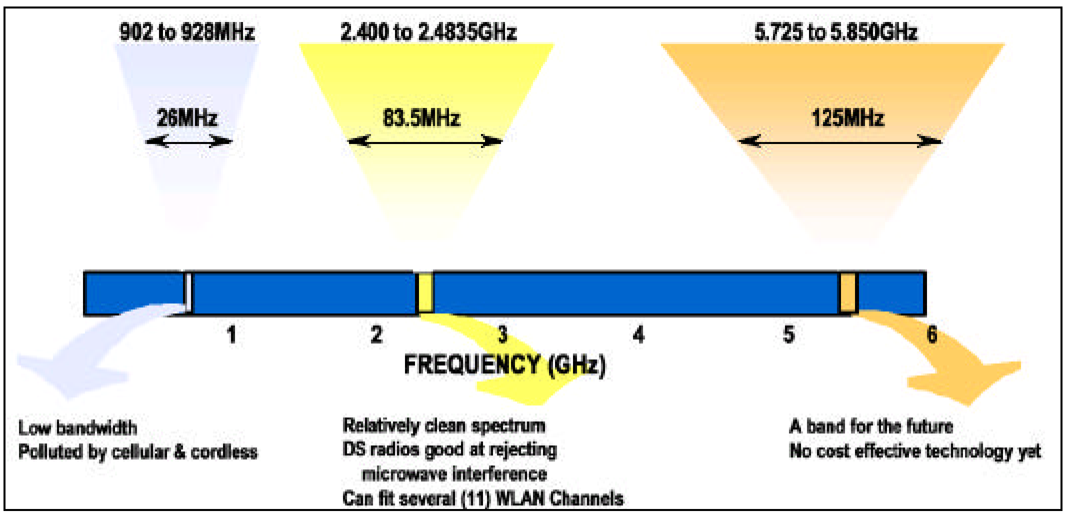

Figure 1. Wireless LAN generations Frequency band. From REF [12].

The fourth and the latest generation of Wireless LAN technology, offering users data rates of 10Mb/s and up. Again evolving from advances in semiconductor technology, the products of this generation are operating at a new, higher frequency – the 5GHz band. The initial product operates in the 5.775-5.85GHZ ISM band, and additional bandwidth around 5.2GHz has also been made available. Unlike the lower frequency bands used in prior generations of Wireless LAN, the 5GHz bands do not have as large a number of potential interferers as microwave ovens or industrial-heating systems at

900MHz and 2.4GHz. In addition there is much more bandwidth available at 5GHz-350MHz compared with 83MHz at 2.4GHz and 26MHz at 900MHz. This combination of greater available bandwidth and reduced source of interference makes the 5GHz bands an ideal region in which Wireless LAN products having performance comparable to the achieved by wired networks are being created.

B. BENEFITS OF WIRELESS LAN

The widespread reliance on networking in civilian and military applications and the huge growth of the Internet and online services are strong testimonies to the benefits of shared data and shared resources. With Wireless LANs, users can access shared information without looking for a place to plug in; in addition, network managers can set up networks without installing or moving wires. Wireless LANs offer the following advantages of productivity, convenience, and cost advantages over wired networks:

1. Mobility

Mobility enables users to move in defined distance served by the Wireless LAN without any restrictions. Many job positions required workers to be mobile, such as inventory clerks, healthcare workers, police officers, and emergency- care specialists.

2. Cost and Time Savings

Installing Wireless LAN where it is difficult or expensive to install wired network is one of the ways to reduce cost. Because there is no downtime in Wireless LAN that result from cable fault in a wired network, time can be saved also. Time and flexibility in installing Wireless LAN is much shorter and easier compared to wired networks.

3. Scalability

Adding new users to Wireless LAN is simple. The network can be configured as a peer-to-peer network environment suitable for a small number of users to full infrastructure networks of thousands of users that enable roaming over a wide area.

C. CONFIGURATIONS

1. Independent Wireless LANS

Wireless LANs can be simple or complex. At its most basic form, two PCs equipped with wireless adapter cards can set up an independent network whenever they are within range of one another. The standard refers to this topology as an Independent

Basic Service Set (IBSS) and provides for some measure of coordination by electing one node from the group to act as the proxy for the missing access point or base station found in more complex topologies. See Figure 2.

This type of networks requires no administration or pre-configuration. In this case each client would only have access to the resources of the other client and not to a central server. Installing an access point can extend the range of an ad hoc network, effectively doubling the range at which the devices can communicate.

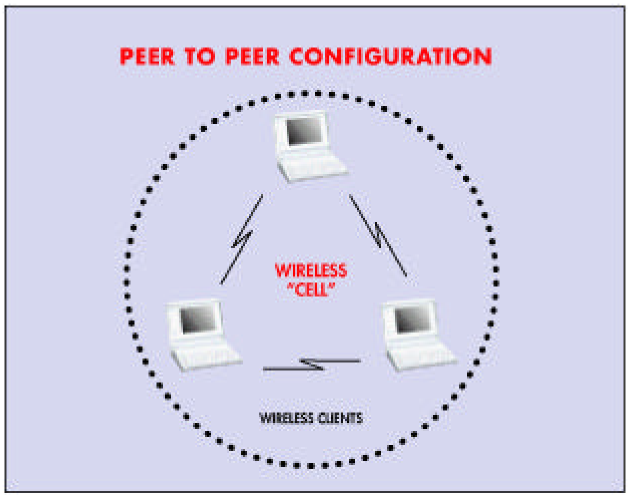

Figure 2. Independent Basic Service Set (IBSS). From REF [12].

2. Infrastructure Wireless LANS

This is a more complex topology, which includes at least one access point or base station. Access points provide the synchronization and coordination, the forwarding of broadcast packets and, perhaps most significantly, a bridge to the wired network.

The standard refers to a topology with a single access point as a Basic Service Set (BSS). A single access point can manage and bridge wireless communications for all the devices within range and operating on the same channel.

To cover a larger area, multiple access points are deployed. This arrangement is called an Extended Service Set (ESS). It is defined as two or more Basic Service Sets connecting to the same wired network. Each access point is assigned a different channel wherever possible to minimize interference and to accommodate many clients; the specific amount depends on the number and nature of the transmissions involved. Many real-world applications exist where a single access point services from 15-50 client devices. Access points have a finite range of approximately 500 feet indoor and 1000 feet outdoor. In a very large facility such as a warehouse, or on a college campus installing more than one access point is probably necessary. See Figure 3.

When users roam between cells or BSSs, their mobile device find and attempt to connect to the access point with the clearest signal and the least amount of network traffic. In this way, a roaming unit can transition seamlessly from one access point in the system to another, without losing network connectivity.

An ESS introduces the possibility of forwarding traffic from one radio cell, the range covered by a single access point, to another over the wired network. This combination of access points and the wired network connecting them is referred to as the Distribution System (DS).

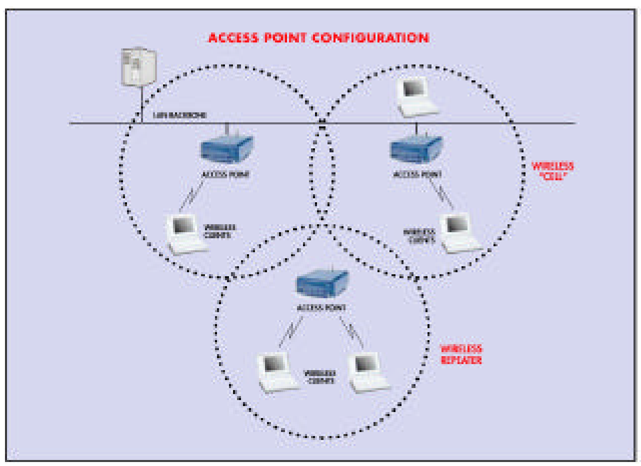

Figure 3. Extended Service Set (ESS). From REF [12].

D. TECHNOLOGY

The following three technologies are used in Wireless LANs: UHF (narrowband) radios, infrared, and spread spectrum radios.

1. UHF (Narrowband)

In this technology a narrowband radio system is used to transmit and receive user information on UHF band frequency. Narrowband radio keeps the radio signal frequency as narrow as possible only to pass the information. Undesirable crosstalk between communication channels is avoided by carefully coordinating different users on different channel frequencies. One drawback of narrowband technology is that the end-user must obtain an FCC license for each site where it is employed.

2. Infrared (IR)

The second technology that is used for Wireless LAN systems is Infra Red, in which communication is carried by light in the invisible part of the spectrum. It is primarily used for very short distance communications, less than three feet from the line of sight connection. It is not possible for the Infra Red light to penetrate any solid material, and it is even attenuated greatly by window glass. Therefore it is not a useful technology compared with Radio Frequency in a Wireless LAN system.

The application where Infra Red comes into its element is as a docking function and in applications where the available power is extremely limited. There is a standard for such products called IrDA that has been developed by Hewlett Packard, IBM and many others. This is found in many notebook and laptop PCs allowing a connectionless docking facility at up to 1Mbps for a desktop machine and at up to two feet, line of sight. Finally this technology is classified in two types:

a. Directed (line-of-sight).

This is a point-to-point communication not a network. This makes units implementing this technology very difficult to operate as a network but does offer increased security since only the user to whom the beam is directed can pick it up.

b. Diffuse technology.

This type spreads the light out and bounces it off walls, ceilings, and buildings so that it reaches a group of end workstations. Attempts to provide wider network capability by using a diffused IR system have been developed and marketed; however, they are limited to 30 -50 feet and cannot go through any solid material.

3. Spread spectrum radios

RF technology employs transmitter and receiver tuned to transmit and receive radio waves at a given frequency range. The transmitter power and the receiver sensitivity help to determine the distance over which they can communicate. High transmission power output is used for long-range communications, while short-range communications require much less power

During World War II, the U.S. military developed spread spectrum techniques for secure voice communications. By operating across a broad range of radio frequencies, a spread spectrum device was able to communicate clearly despite interference from other devices using the same spectrum in the same physical location. In addition to its relative immunity to interference, spread spectrum makes eavesdropping and jamming inherently difficult. To decode the signal from a spread spectrum device, a receiver must know the specific spreading pattern of the transmitter.

In commercial applications, spread spectrum techniques currently offer data rates up to 2Mbps. Because the FCC does not require site licensing for the bands used by spread spectrum systems, this technology has become the standard for high-speed RF data transmission. Two modulation schemes are commonly used to encode spread spectrum signals: direct sequence and frequency hopping.

a. Frequency Hopping Spread Spectrum (FHSS)

In a Frequency Hopping Spread Spectrum (FHSS) system, the data is modulated on to the carrier in a manner identical to that employed for standard narrow band communications. Most frequency hopping systems employ Gaussian Frequency Shift Keyed modulation, with either two or four levels. The carrier frequency is then changed (hopped) to a new frequency in accordance with a pre-determined hopping sequence. If the receiver frequency is then hopped in synchronism with the transmitter, data is transferred in the same manner as if the transmitter and receiver were each tuned to a single fixed frequency. If different transmitter-receiver pairs hop throughout the same band of frequencies but using different hopping sequences, then multiple users can share the same frequency band on a non-interfering basis. See Figure 4.

In the 2.4GHz band, there are 79 1.0MHz wide channels assigned, and a total of 78 different hopping sequences. In theory, all 78 hop sequences could be shared on a non-interfering basis, but statistically only about 15-20 (depending on individual user data traffic patterns) can be used. Thus a network manager could assign 15 different hopping sequences in the same physical area with minimal interference. This has the effect of multiplying the total available bandwidth by 15 times; nevertheless, each individual user would only experience a 2 Mb/s maximum data rate.

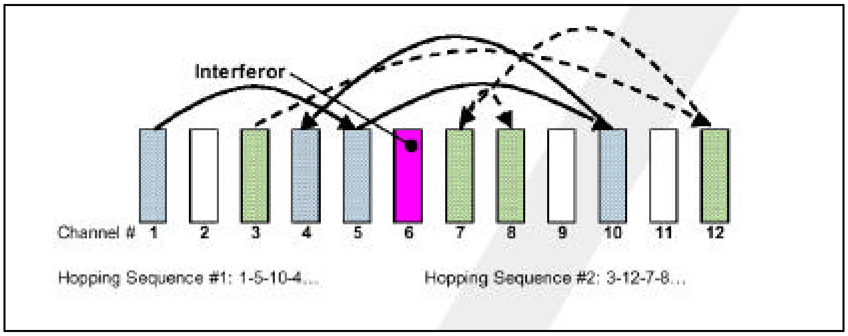

Figure 4. Frequency Hopping Spread Spectrum (FHSS). From REF [12].

b. Direct Sequence Spread Spectrum (DSSS)

The second type of spread spectrum is known as Direct Sequence Spread Spectrum (DSSS). In this technology, the data stream is multiplied by a pseudo-random spreading code to artificially increase the bandwidth over which the data is transmitted. The resulting data stream is then modulated onto the carrier using either Differential Binary Phase Shift Keying or Differential Quadrature Phase Shift Keying. By spreading the data bandwidth over a much wider frequency band, the power spectral density of the signal is reduced by the ratio of the data bandwidth to the total spread bandwidth. In a DSSS receiver, the incoming spread spectrum data is fed to a correlator where it is correlated with a copy of the pseudo-random spreading code used at the transmitter. Since noise and interference are, by definition, de-correlated from the desired signal, the desired signal is then extracted from a noisy channel.

While the block diagram of a DSSS Wireless LAN product is somewhat simpler than a FHSS product, there are some very subtle difficulties that come into play in the presence of strong interfering signals. See Figure 5.

The basis of the noise immunity of a DSSS system is the fact that the desired signal and interference or noise is uncorrelated. In complex interference environments, which are becoming more common as usage increases, particularly ones in which very strong signals may be present, non-linearities in the receiver generate InterModulation distortion products between the desired signal and the interfering signals. These IM products are now correlated with the desired signal thus reducing the resulting signal to a noise ratio when processed in the receiver. See Figure 5.

The usual implementation of DSSS in the 2.4GHz band employs a 13MHz wide channel to carry a 1MHz signal. Channels are centered at 5MHz spacing, giving significant overlap. Within the designated 2.4 to 2.483GHz band, eleven channels are available for users in the US. In a practical network, three non-overlapping channels are typically available for deploying a network. In an analogous manner as described for FHSS, the total bandwidth in a physical region could effectively be multiplied by a factor of three for DSSS networks, although each user would again only experience two Mb/s throughput.

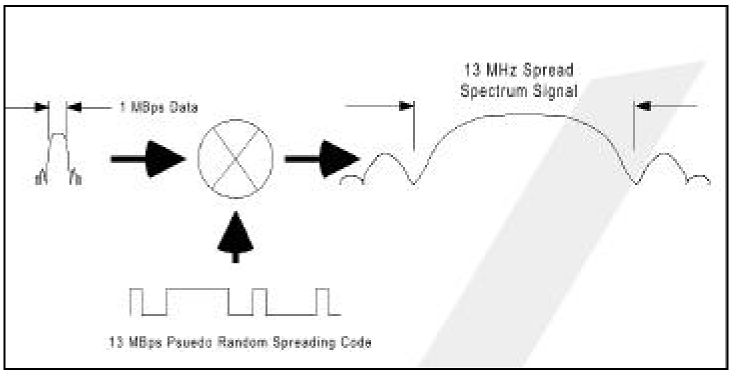

Figure 5. Direct sequence Spread Spectrum. (DSSS). From REF [12].

E. WIRELESS LAN STANDARDS

With many wireless systems and applications from many suppliers in many countries, the need for standardization is essential. As a result, cooperation between wireless manufacturer and user interest groups has given rise to the creation of open association to develop standards. See Figure 6. The standards used for Wireless LAN is summarized in the following paragraphs:

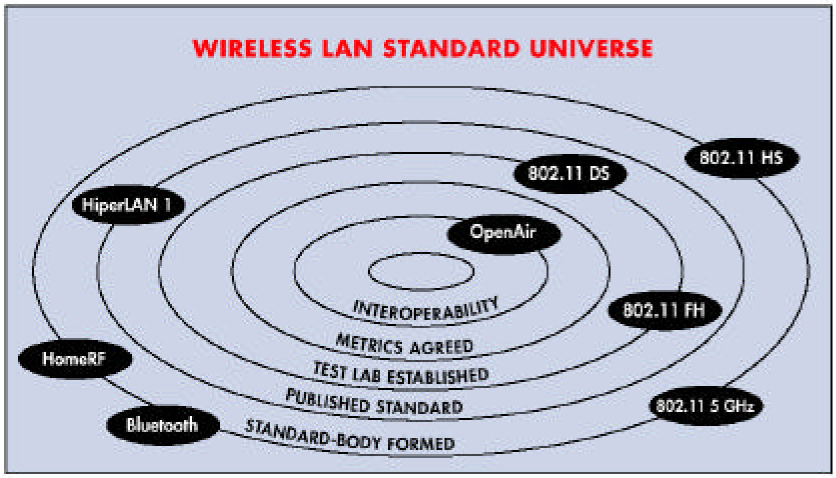

Figure 6. Wireless LAN Standard Universe. From REF [12].

1. IEEE 802.11

In 1990 the IEEE 802 standards groups for networking setup a specific group to develop a Wireless LAN standard similar to the Ethernet standard. On June 26, 1997, the IEEE 802.11 Wireless LAN Standard Committee approved the IEEE 802.11 specification. The standard is a detailed software, hardware and protocol specification with regard to the physical and data link layer of the Open System Interconnection (OSI) reference model that integrates with existing wired LAN standards.

The Specifications of IEEE 802.11 define two layers: layer one is called Physical Layer (PHY) and layer two is called Media Access Control (MAC) layer. Layer one specifies the modulation scheme used and signaling characteristics for the transmission through the radio frequencies; whereas, layer two defines a way of accessing the physical layer, it also defines the services related to the radio resource and the mobility management.

The physical layer defines three technologies: Frequency Hopping 1Mb/s, Direct Sequence 1 and 2Mb/s and diffuse infrared. Since then, it has been extended to support 2Mb/s for Frequency Hopping and 5.5 and 11Mb/s for Direct Sequence (IEEE 802.11b). The MAC layer has two main standards of operation, a distributed mode (CSMA/CA), and a coordinated mode (polling mode - not much used in practice). The optional power management features are quite complex. The IEEE 802.11 MAC protocol also includes optional authentication and encryption by using the Wired Equivalent Privacy (WEP). On the other hand, IEEE 802.11 lacks defining some areas such as multirate, roaming, inter Access Point (AP) communication, etc, that might be covered by future developments of the standard or complementary standards.

2. Home RF

The Home RF is a group of companies from different background formed to push the usage of Wireless LAN in the home and the small office. This group is developing and promoting a new Radio LAN standard.

The MAC protocol is implemented in software so it does not contribute much to the final cost of the product. A new MAC protocol has been designed, much simpler, combining the best feature of (An ETSI digital cordless phone standard) DECT and IEEE 802.11: a digital cordless phone and ad-hoc data network, integrated together.

The voice service is carried over a classical (Time Division Multiple Access) TDMA protocol. The data part uses a (Carrier Sense Multiple Access with Collision Avoidance) CSMA/CA access mechanism similar to IEEE 802.11 to offer a service very similar to Ethernet.

The 1 Mb/s Frequency Hopping physical layer (with optional 2 Mb/s using 4FSK) allows 6 voice connections and enough data throughput for most users in the Home. The voice quality should be equivalent to DECT in Europe and more advance than any current digital phone in the US. Data performance should be slightly lower than IEEE 802.11. The MAC protocol has also been designed in a very flexible way, allowing the development of very cheap handsets or data terminals and high performance multimedia cards for PCs.

3. OpenAir standard

OpenAir is the proprietary protocol from Proxim. Proxim is one of the largest Wireless LAN manufacturer. OpenAir is a pre-IEEE 802.11 protocol, using Frequency Hopping and 0.8 and 1.6 Mb/s bit rate (2FSK and 4FSK). The radio turnaround (size of contention slots between packets) is much larger in IEEE 802.11, which allows a cheaper implementation but reduces performance. The OpenAir MAC protocol is CSMA/CA with MAC retransmissions. A nice feature of the protocol is the access point sending all its traffic contention free at the beginning of each dwell and then switching the channel back to contention access mode. OpenAir does not implement any encryption at the MAC layer, but generates Network ID based on a password (Security ID). This provides some security.

4. HiperLAN

HiperLAN is opposite of IEEE 802.11. This standard has been designed by a committee of researcher within the ETSI, without strong vendors influence, and is quite different from existing products. The standard is quite simple and uses some advanced features. The first main advantage of HiperLAN is that it works in a dedicated bandwidth of 5.1 to 5.3GHz, allocated only in Europe; therefore, it does not have to include spread spectrum. The signaling rate is 23.5Mb/s, with 5 fixed channels being defined. The protocol uses a variant of CSMA/CA based on packet Time To Live and priority, and MAC level retransmissions. The protocol includes optional encryption and saves power. The best feature of HiperLAN is the ad-hoc routing: in which if a destination is not reached, intermediate nodes will automatically forward it through the optimal route within the HiperLAN network. HiperLAN is also totally ad-hoc, requiring no configuration and no central controller. The main deficiency of HiperLAN standard is that it does not provide real isochronous servic es.

5. HiperLAN II

HiperLAN II is opposite of HiperLAN. The first HiperLAN was designed to build ad-hoc networks; the second HiperLAN was designed for managed infrastructure and wireless distribution systems. The only similarity of HiperLAN II is being specified by the ETSI (Broadband Radio Access Network group), operated at 5GHz (5.4 to 5.7GHz) and dedicated to a band in Europe.

HiperLAN II was the first standard to be based on Orthogonal Frequency Division Multiplexing (OFDM) modulation. Each sub-carrier may be modulated by different modulations, which allow multiple bit-rates (6, 9, 12, 18, 27 and 36Mb/s, with optional 54Mb/s) with performance around 25 Mb/s bit-rate. The channel width is 20MHz and includes 48 OFDM carriers used to carry data with 4 additional ones used as references.

HiperLAN II is a Wireless ATM system, while the MAC protocol is a TDMA scheme centrally coordinated with reservation slots. HiperLAN II also defines powersaving and security features designed to carry ATM cells, IP packets, and digital voice (from cellular phones). The main advantage of HiperLAN II is that it can offer better quality of service (low latency) and differentiated quality of service (guarantee of bandwidth).

6. Bluetooth

Bluetooth, the subject of this thesis, is the code word of a new emerging technology for PANs, which is a new type of network. Bluetooth is considered as a complement to the Wireless LAN not as a replacement. Detail for this technology is covered in chapter III.

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III. BLUETOOTH TECHNOLOGY

This chapter gives a short overview of Bluetooth technology with eight sections. Section B introduces Bluetooth and covers background and the origin of this technology. Section C describes the protocol stack with emphasis on the data part since this thesis does not cover audio handling. More detail is explained in the Specifications [10]. Section D covers the piconet and scatternet topology concept. Section E summaries the standard of PAN, which involves Bluetooth, and finally section F covers the benefits of this technology.

A. INTRODUCTION AND BACKGROUND

Most of the devices and equipment available today are connected through cables, such as a computer and its peripherals. Ideas of how to make things better by removing cables and replacing them with wireless communication have grown from simple ideas to reality. Bluetooth wireless technology is the world's new RF transmission standard for small form factor, low cost, and short-range radio links between portable or desktop devices. The technology also has been designed for ease of use, simultaneous voice and data, and multi-point communications. It eliminates the confusion of cables, connectors and protocols confounding communications between today's high tech products.

The increase in the number of users, and the constant shrinking of portable computers, as well as the trend toward the replacement of desktop computers by portable ones, form an ideal market environment that eliminates the annoying cable and its limitations regarding flexibility and range.

In 1994 Ericsson Mobile communications began a study to examine an alternative to the cables that linked their mobile phones with accessories. The study looked at using radio links because it has the advantage of complete directional transmission and obstacle penetration lacking in existing technology like IR. Many requirements of the study included handling both voice and data, in order to connect phones to both headset and computing devices.

Ericsson realized that the technology was more likely to be widely accepted and powerful, if adopted and refined by an industry group that could produce an open, common specification. In response to this, the Special Interest Group (SIG) was founded. Founding companies of the SIG are Ericsson, Intel Corporation, IBM, Nokia Corporation and Toshiba Corporation. The SIG was publicly announced in May 1998 with a charter to produce an open specification for hardware and software promoting interoperable, cross-platform implementations for all kinds of devices. In 1999 the group published version 1.0 of the Specifications, and in Feb. 2001 version 1.1 of the Specification was published.

The Bluetooth Specifications are open to manufacturers in the SIG. A key feature of the Specifications is that it aims to allow devices from many different manufacturers to work with one another. This means that the Specification defines the radio system and the software stack enabling applications to find other Bluetooth devices in the area, discover what services are offered and use those services. The Specifications are divided into two main parts, core specifications covering protocol layers and stack, and profiles giving detail of how user applications should use the protocol stack. As the specifications evolved and awareness of the technology and the SIG increased, many other companies joined the SIG as adopters. Today there are over 2490 adopter members of the SIG.

The code name Bluetooth was taken from the name of the tenth-century Danish king, Harald Bluetooth (Danish Harald Blåtand). He was the King of Denmark between 940 and 985 AD. The name "Blåtand" was probably taken from two Old Danish words, 'blå' meaning dark skinned and 'tan' meaning great man. The Danish king united and controlled Denmark and Norway at that time. The name was adopted because Bluetooth wireless technology is expected to unify the telecommunications and computing industries.

B. BLUETOOTH PROTOCOL STACK

The Specifications divide the protocol stack into four layers according to their purpose including the question of whether Bluetooth SIG has been involved in specifying these protocols. The protocols fall into following layers.

1. Bluetooth Core Protocols layer

The Bluetooth Core Protocols comprise exclusively Bluetooth-specific protocols developed by the Bluetooth SIG. It encompasses the radio, Baseband and Link Control Protocol (LC), Link Manager Protocol (LMP), Logical Link Control and Adaptation

Protocol (L2CAP), and Service Discovery Protocol (SDP). This layer is sometimes called the lower layer of the stack and is required by most of Bluetooth devices.

Bluetooth radio is a short distance, low power radio operating in the unlicensed spectrum of 2.4GHz. Included are three transmit power classes with nominal output power of 0, +4 and +20dBm with three steps of power control mandated for the high-power class. To operate at high power in the unlicensed bands, and to avoid interference, Bluetooth transceiver uses FHSS (chapter II) with a nominal rate of 1600hop/s. The access method is TDMA with 625 μs frames and half-duplex (Tx and Rx alternate in time) connections and frequency hops between each transmit and receive signal. The hop sequence is pseudo-random with the largest possible hop of 78MHz. The modulation type used is Gaussian FSK in which Gaussian filter make the pulse smoother to limit its spectral width.

The Baseband and Link Control Protocol enables the physical RF link between Bluetooth units. Since the Bluetooth RF is a FHSS system in which packets are transmitted in defined time slots and frequencies, this layer uses inquiry and paging procedures to synchronize the transmission hopping frequency and clock of the different Bluetooth devices. The system provides two different kinds of physical links with their corresponding Baseband packets, Synchronous Connection-Oriented (SCO) and Asynchronous Connectionless (ACL), which transmit in a multiplexing manner on the same RF link. ACL packets are used for data only, while the SCO packets contain audio only or a combination of audio and data. All audio and data packets can have different levels of error correction and be encrypted. The audio part is not going to be covered in this thesis but further details are covered in the Specifications in Ref [10].

The Link Manager Protocol (LMP) is responsible for link set-up between Bluetooth devices. This includes security aspects like authentication and encryption by generating, exchanging and checking of link and encryption keys, and the control and negotiation of Baseband packet size. Furthermore LMP controls the power modes and duty cycles of the Bluetooth radio device, and the connection state of the Bluetooth unit.

The Bluetooth logical link control and adaptation protocol (L2CAP) adapts upper layer protocols over the Baseband. Presumably, The protocol works in parallel with LMP except in when the L2CAP provides services to the upper layer the payload data is not sent as LMP messages. Additionally this protocol provides connection-oriented and connectionless data services to the Upper layer protocols with protocol multiplexing capability, segmentation and reassembly operation, and group abstractions. It also permits higher-level protocols and applications to transmit and receive L2CAP data packets up to 64 kilobytes in length. Although the Baseband protocol provides the SCO and ACL link types, L2CAP is defined only for ACL links and no support for SCO links is specified in Bluetooth Specification.

Discovery services are a crucial part of the Bluetooth framework. These services provide the basis for all the usage models. Using Service Discovery Protocol (SDP), device information, services and their characteristics can be queried and a connection between two or more Bluetooth devices is established.

2. Cable Replacement Protocol layer

This layer is also developed by the Bluetooth SIG but based on the ETSI TS 07.10 and has RFCOMM protocol. RFCOMM is cable replacement protocol, which emulates RS-232 control and data signals over Bluetooth Baseband, providing both transport capabilities for upper level services (e.g. OBEX) that use serial line as transport mechanism.

3. Telephony Control Protocol layer (TCS)

This layer is also developed by the Bluetooth SIG and based on ITU-T Recommendation Q.931. It has two protocols, TCS binary that is a bit-oriented protocol defining the call control signaling for the establishment of speech and data calls between Bluetooth devices. In addition, this protocol defines mobility management procedures for handling groups of Bluetooth TCS devices.

The second protocol is TC-AT Commands, a set of commands by which a mobile phone and modem can be controlled in the multiple usage models. This is in addition to the commands used for FAX services.

4. Adopted Protocols layer

The Adopted protocol layer forms application-oriented protocols enabling applications to run over the Bluetooth core protocols. The point-to-point protocol, one used in this layer, is designed to run over RFCOMM to accomplish point-to-point connections.

The TCP/UDP/IP protocols are standard protocols defined for communication across the Internet. The implementation of these standards in Bluetooth devices allows for communication with any other device connected to the Internet.

The OBEX protocol is a session protocol developed by the Infrared Data Association (IrDA) to exchange objects in a simple and spontaneous manner. OBEX, which provides the same basic functionality as HTTP but in a much lighter fashion, a client-server model is used. This protocol is independent of the transport mechanism and transport API, provided it recognizes a reliable transport base. Along with the protocol itself, and the "grammar" for OBEX conversations between devices, OBEX provides a model for representing objects and operations.

Hidden computing usage models can be implemented using the Wireless Application Protocol (WAP) features. The WAP Forum is building a wireless protocol specification that works across a variety of wide-area wireless network technologies. The goal is to bring Internet content and telephony services to digital cellular phones and other wireless terminals.

C. PROFILES

Profiles define the protocols and protocol features supporting a particular usage model. Bluetooth SIG has specified the profiles for these usage models. In addition to these profiles, four general profiles are given that are widely utilized by these usage model oriented profiles. These are the generic access profile (GAP), the serial port profile, the service discovery application profile (SDAP), and the generic object exchange profile (GOEP).

The file transfer usage model offers the ability to transfer data objects from one device (e.g., PC, smart-phone, or PDA) to another. Object types include, but are not limited to, .xls, .ppt, .wav, .jpg, and .doc files, entire folders or directories or streaming media formats. This usage model also offers a possibility to browse the contents of the folders on a remote device.

The Internet Bridge usage model, mobile phone or cordless modem acts as a modem to the PC, providing dial-up networking and fax capabilities without need for physical connection to the PC.

The LAN Access usage model, and multiple data terminals use a LAN access point as a wireless connection to a LAN. Once connected the data terminals operate as if they were connected to a LAN via dialup networking. The data terminal can access all of the services provided by the LAN. The synchronization usage model provides a device-to-device synchronization.

D. COMPARING BLUETOOTH PROTOCOL STACK TO OSI MODEL

Since the OSI reference model is an ideal model, the comparison serves to highlight the division of responsibility in the Bluetooth stack. The physical layer is responsible for the electrical interface to the communications media, including modulation and channel coding. It therefore covers the radio and part of the Baseband in Bluetooth.

The Data link Layer is responsible for transmission, framing, and error control over a particular link, therefore, overlapping the link controller task and the control end of the Baseband, including error checking and correction. The network layer is responsible for data transfer across the network, independent of the media and specific topology of the network. This encompasses the higher end of the link controller, setting up and maintaining multiple links, and also covering most of the link manager task.

The transport layer is responsible for the reliability and multiplexing of data transfer across the network to the level provided by the application. As a result, the layer overlaps at the high end of the Link Manager covering the Host Controller Interface (HCI), which provides the actual data transport mechanisms. The session layer provides the management and data flow control services, covered by L2CAP and the lower ends of the RFCOMM/SDP. The presentation layer provides a common presentation for application layer data by adding service structure to the units of data, which is the main task of RFCOMM/SDP. Finally, the application layer is responsible for management between user applications. See Figure 7.

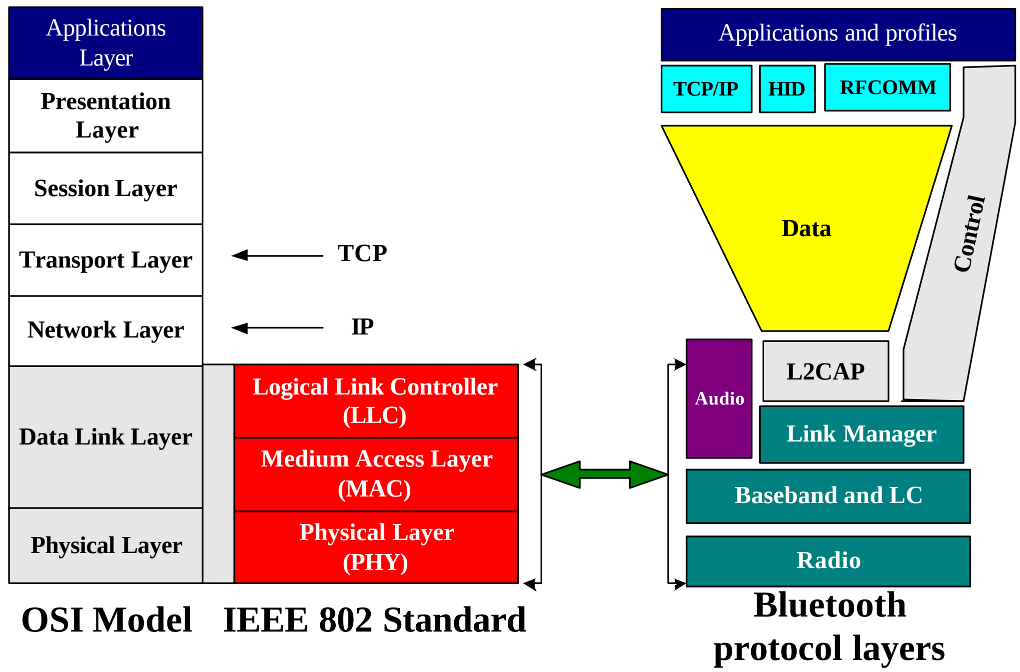

Figure 7. Bluetooth Protocol stack and OSI model.

E. TOPOLOGY

1. Master and Slave Rules

Bluetooth devices can operate in two modes: as a Master or as a Slave. The Master sets the frequency hopping sequence, and Slaves synchronize to the Master in time and frequency by following the Master's hopping sequence.

Every Bluetooth device has a unique Bluetooth device address (MAC address), and a Bluetooth clock. When Slaves connect to the Master, they are given the Bluetooth Device Address and clock of the Master. The Slaves then use that information to calculate the frequency hop sequence and synchronize themselves to it.

In addition to controlling the frequency hop sequence, the Master controls when devices are allowed to transmit. The Master allows Slaves to transmit by allocating slots for voice traffic or Data traffic. In data traffic slots, the Slaves are only allowed to transmit when replying to a transmission by the Master. In voice traffic slots, Slaves are required to transmit regularly in reserved slots whether or not they are replying to the Master.

A Master mode starts its transmission on even-numbered slots. Likewise, a Slave starts its transmissions on odd numbered slots. See Figure 8. Furthermore the Master controls the division of available bandwidth among the Slaves by deciding when and how often to communicate with each Slave. See Figure 8.

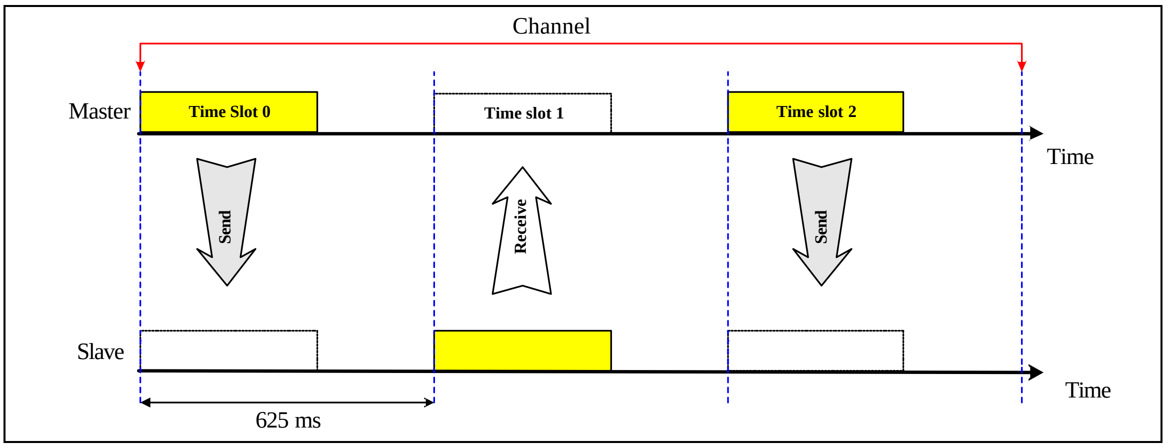

Figure 8. Master and Slave slots.

2. Piconets and Scatternets

A collection of Slave devices operating together with one common Master is called a piconet. If there is only one Slave with that Master then it is a point-to-point connection, however, if there is more than one Slave Mastered by that Master, then it is a point to multipoint connection. The Slaves in a piconet only have links to the Master and with no direct links between Slaves in piconet. See Figure 9.

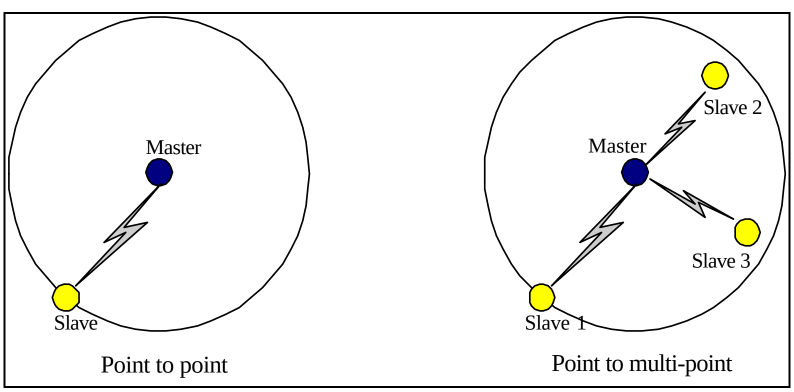

Figure 9. Piconet.

The maximum number of Salves in a piconet is seven, with each Slave communicating only with a shared Master. However a large coverage area or greater number of network members can be covered by linking many Piconets into scatternet, where some devices are members of more than one piconet. When a device is linked to more than one piconet, it must time share, spending a few slots on one piconet and a few slots on the other. A device can not be a Master of two different Piconets. The current Specification also limits the number of Piconets within a scatternet to 10 Piconets. See Figure 10.

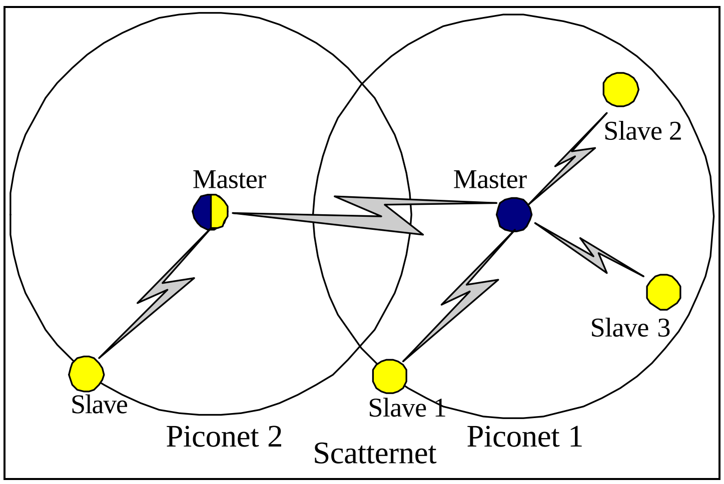

Figure 10. Scatternet.

3. Physical Links

Like other communication technologies, Bluetooth wireless technology uses serial communication to transmit data in binary form. Serial communications entail the transmission of data in sequential fashion. The problem with serial data communication is synchronizing the receiver with the sender, so the receiver can correctly detect the beginning of each new character in the bit stream. There are two approaches to serial data transmission that solve the problem of synchronization.

The first approach is Asynchronous Transmission; synchronization is established by bracketing each set of 8 bits by a start and stop bit. With this link the transmitter and receiver only have to approximate the same clock rate. For a 1 to 10-bit sequence, the last bit is interpreted correctly even if the sender and receiver clock differ by as much as 5%.

This type of link is simple and inexpensive, however, includes high overhead since each byte carries at least two extra bits for the start-stop function, resulting in a 20% loss of bandwidth.

The second approach is Synchronous transmission, which relies on accurate timing between the sending and receiving devices in order to identify of the bit stream during decoding. If both devices use the same clock source, then transmission takes place with the assurance that the receiver accurately interprets the bit stream. To guard against the loss of synchronization, the receiver is periodically brought into synchronization with the transmitter through the use of control bits embedded in the bit stream. In this type of communication the data bits are sent as packets in reserved time slots that are set up between the two devices. This process is more efficient in the use of bandwidth and the packet structure allowing for easy handling of control information.

Two basic types of physical links that can be established between Master and Slave in a Bluetooth piconet are an ACL link and a SCO link. An ACL link provides a packet-switched connection when data is exchanged sporadically and when data is available from higher up the stack. A Master may have a number of ACL links to a number of different Slaves at any one time, but only one link can exist between any two devices. Thus the Master on a slot-by-slot basis controls the choice of which Slave to transmit to and receive from. Most ACL packets facilitate error checking and retransmission to assure data integrity. A Slave responds with an ACL packet in the next Slave-to-Master slot. If the Slave fails to decode the Slave address in the packet header, it does not know whether it was addressed and, therefore, does not respond.

SCO link provides a symmetrical link between Master and Slave with reserved channel bandwidth and regular periodic exchange of data in the form of reserved slots. Thus, the SCO link provides a circuit-switched connection where data is regularly exchanged. A Master can support up to three SCO links to the same Slave or to different Slaves.

4. Logical Channels

There are five logical channels defined in the Bluetooth Specifications, which are carried over the physical links mentioned above. The Link Control Logical Channel carries low-level link control information in every packet that has a packet header. The Link Manager Logical Channel carries control information exchange between the link managers of the Master and one or more Slaves. The User Asynchronous Logical Channel carries asynchronous user data. The User Isochroous Logical Channel is used for time-bounded information like compressed audio over an ACL link. Finally the User-Synchronous data logical channel carries transparent synchronous user data carried over SCO link.

F. 802.15 STANDARD

IEEE 802.15 Working Group is part of the 802 Local and Metropolitan Area Network Standards Committee of the IEEE Computer Society. The 802.15 WPAN™ effort focuses on the development of standards for wireless networking of portable and mobile computing devices such as PCs, Personal Digital Assistants (PDAs), peripherals, cell phones, pagers, and consumer electronics, allowing these devices to communicate and interoperate with one another. The goal of the Working Group is to create standards that have broad market applicability dealing effectively with the issues of coexistence and interoperability with other wireless networking solutions. The working group is further divided into four task groups and a Publicity Committee group.

Task Group 1 - WPAN/Bluetooth™: derives a Wireless Personal Area Network™ standard based on the Bluetooth v1.x Foundation Specification's. Group scope and purpose are in defining PHY and MAC specifications for wireless connectivity with fixed, portable and moving devices within or entering a Personal Operating Space (POS), extending up to 10 meters in all directions.

G. BENEFITS AND ADVANTAGES

1. Cables elimination

Bluetooth will allow their manufacturers of different products to incorporate the technology into products for a few dollars per device. Because the cost of a cable and connectors can easily exceed this amount, Bluetooth represents a technology that afford users the ability to replace many standard and proprietary cabling schemes for connecting devices with one universal short-range wireless communication method. Although the cost to incorporate Bluetooth technology into a limited number of products during 2000 was slightly over $20 per unit, this cost is expected to decline considerably. According to several market analysts, the cost of incorporating Bluetooth into PDAs, cell phones, computer peripherals, and other products could fall to under $5 per unit.

2. Open Specifications

The Bluetooth wireless technology specifications is publicly available and royalty free.

3. Enhancing PAN applications

A Wireless PAN is short-distance wireless network specifically designed to support portable and mobile computing devices, such as PCs, PDAs, wireless printers and storage devices, cell phones, pagers, and a variety of consumer electronics equipment. Bluetooth allows devices within close proximity to join together in ad hoc wireless networking order to exchange information. It also provides the bandwidth and convenience to make data exchange practical for mobile devic es. This provision overcomes many of the complications of other mobile data systems, such as cellular packet data systems requiring modems and connections through low bandwidth cellular links.

4. Voice and data handling

Bluetooth wireless communications makes provisions for both voice and data, and thus it is an ideal technology for unifying these worlds by enabling all sorts of devices to communicate using either or both of these content types.

5. Any where in the world

Bluetooth wireless communications operates within a chosen frequency spectrum that is unlicensed throughout the world (with certain limitations and restrictions). Thus devices that employ Bluetooth wireless communications can be used unmodified, no matter where a person might be.

6. Auto discovery and configuration

Bluetooth devices do not need to be configured to run. These devices are always on, that is running in the background allowing devices to communicate with each other as soon as they come within range. This flexibility replaces the user requirement of opening an application or pressing a button to initiate a process. Additionally these devices facilitate network administrator tasks in adding new user to the network.

7. Unlimited Number of Applications

This new technology has opened the door for both civilian and military wireless PAN applications. One example of how this technology helps in the navy where a lot of sensors and gauges are connected. Bluetooth would eliminate the need for these wires associated with sensors and gauges connected to the monitoring rooms. In addition sensors and gauges could be easily installed in difficult places.

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IV. IEEE 802.11 WIRELESS LAN VERSUS BLUETOOTH

Sharing the same frequency range, Bluetooth and the IEEE 802.11 standard for wireless LANs have often been categorized as competitive technologies. In fact, they are complementary rather than competitive. In this chapter some of the major differences between the two technologies will be discussed.

A. BIT RATE (THROUGHPUT)

The IEEE 802.11 has a data rate of 5.5-11Mb/s, which is higher than the Bluetooth that has 1Mb/s. This is due to the high hopping frequency of Bluetooth (1600 hop/sec), which was designed to enhance its efficiency against interference and eavesdropping, and delay caused by switching between hoping frequency. These elements limit the maximum length of the data blocks and the handling of a higher data rate by the Bluetooth channel.

B. RANGE AND OUTPUT POWER

The nominal range for Bluetooth reception is 33 feet when using 0-dBm transmit power, although the range can be extended to as much as 330 feet using an external power amplifier to boost the transmit power to +20 dBm. REF [10]. The IEEE 802.11 has a transmission range of around 50-500 feet indoor and 990 feet outdoors. The standard allows transmission power of 1000 mW in North America (and less in other parts of the world). REF [10].

C. SECURITY

Bluetooth device uses PIN (Personnel Identification Number) codes and Bluetooth Device Address to identify other Bluetooth devices. The high hopping frequency is said to add protection against eavesdropping on the connection. For further enhancing security, Bluetooth uses Linear Feedback Shift Register for encryption. The effective key length of the algorithm is selectable between 8 or 128 bits.

The security setup for a Bluetooth connection is done in the software layer. An inexperienced or careless user can cause the level of security to decrease to almost zero.

The IEEE 802.11 networks are based on absence of privacy, since the access point in the system is acting as a hub in a wired network. The basic nature of a hub is to repeat all packets it receives from any device to every device in the network .

The IEEE 802.11 standard includes an optional encryption capability Wired Equivalent Policy (WEP), which is implemented by embedding a security algorithm in the media access controller (MAC). The passwords are stored in the access points and on each mobile computer. It encrypts the transmissions between the access point and the mobile devices. All the devices use the same password in a network. Obviously the encryption does not give much security in a public network, since it would have to publish the password. The encryption key used in WEB has 64 bits in its encryption key.

D. INTERFERNCE AND ROBUSTNESS

The 2.4GHz ISM radio frequency band is a broad, free and unlicensed spectrum space, an attractive band for the designers of portable data devices. But all of these devices have the potential of interfering with each other.

Interestingly, neither Bluetooth nor IEEE 802.11 Wireless LAN was designed with specific mechanisms to combat the interference that each creates for the other. As a fast frequency-hopping system, Bluetooth assumes that it will hop away from bad channels, minimizing its exposure to interference. The IEEE 802.11 Wireless LAN MAC layer, based on the Ethernet protocol, assumes that many stations share the same medium, and, therefore, if a transmission fails, it is because of two IEEE 802.11 Wireless LAN stations transmitting simultaneously.

Bluetooth transmits with low power compared to IEEE 802.11 Wireless LAN; therefore, more powerful devices will overwhelm its signal. At the circuit level of a device transfer data is impossible using both of the Specifications at the same time, since they are utilizing the same radio frequencies, and shielding themselves from the other's interference may not be possible. This situation limits the coexistence of the standards.

The IEEE 802.15 is trying to improve the coexistence of the two standard. The standard committee and venders are trying to make changes to prevent the collisions of the data transfer. The goal is to decrease the probability of Bluetooth and IEEE 802.11 devices transmitting at the same time. To do this the group suggested that in the presence of Bluetooth, IEEE 802.11 has to use direct sequence high rate devices, which has been proven to be reliable.

Another recommendation is to avoid having Bluetooth products transmit within 50 feet of IEEE 802.11 radios and Access points. The relatively low power signals of the Bluetooth devices rapidly diminish over a long distance. If these recommendations are not feasible or do not provide adequate results, then the distance between IEEE 802.11 radios and Access points should be decreased. This strengthens the IEEE 802.11 Wireless LAN signals, reducing the affects of Bluetooth interference.

Bluetooth may be able to handle this interference by using its narrowband fast frequency-hopping scheme that uses pseudo-hop pattern and short data packets. Furthermore, the use of Forward Error Correction (FEC) decreases the number of needed retransmissions by adding redundant data to the data stream.

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V. BLUETOOTH AND SENSORS

There is no specific profile for sensor applications among the profiles mentioned in Chapter III. Additionally Bluetooth was not mainly developed with the sensor market in mind. However, Bluetooth can very well be used to perform wireless transmissions in many kinds of sensor systems.

This chapter gives an overview about sensors in section A, and discusses the Host Controller Interface in section B. Finally the different approaches to connect a sensor to a Bluetooth module are discussed.

A. SENSORS

Sensors are defined as data producers. In their most basic form, a physical sensor senses changes in physical quantities and converts that to an analog signal for processing. There are two major types of sensors: Active and Passive sensors. Active sensor systems interact with the environment and observe how their actions affect the environment. Passive sensor systems sense ambient radiation or signals.

Active systems work by actively controlling a probe signal in the environment and observing how this interacts with the environment causing sensible changes. Actively probing the environment helps to remove ambiguities from a passive sensor view. Because these systems irradiate their environment, they leave a detectable signature on the environment. In contrast, passive systems simply receive information passively. and are useful in situations where irradiating the environment is undesirable or impossible.

Sensor outputs are generally only useful to specific systems that have a straightforward connection to the sensed input, such as connecting the sensor to a Bluetooth module.

B. HOST CONTROLLER INTERFACE (HCI)

The Host Controller Interface (HCI) allows higher layers of the stack, including applications, to access the module through a single standard interface. The radio, Baseband and link manager are packaged together into a Bluetooth module. See Figure

11. The module is then attached to a host device (sensor), enabling that device with Bluetooth wireless communication.

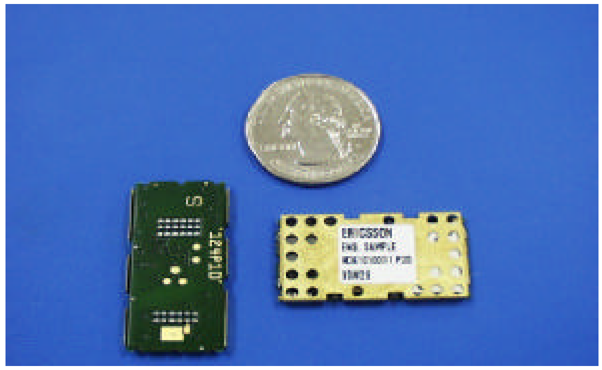

Figure 11. Bluetooth module.

The Specifications in REF [10] defines the physical interface between the module and the host device via the host transport (RS232, USB, UART). The Specifications also defines a common interface for accessing the module independently of a particular physical interface. Through HCI commands, the module may enter certain modes of operation. Through HCI events, higher layers of the stack can be informed of the results of a device operation. The data passes through the HCI as it is transmitted or received by the host. See Figure 12.

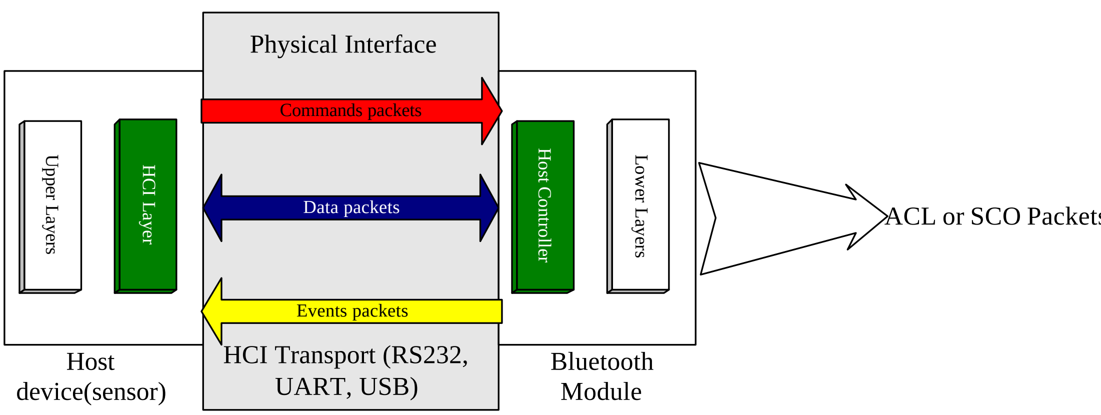

Figure 12. Host Controller Interface packets.

C. CONNECTING A SENSOR TO BLUETOOTH

Using Bluetooth technology with sensing devices has many advantages over other Wireless LAN technology available. These advantages are summarized in the following points.

- Robust connection with Spread Spectrum.
- Ability to communicate with both high-speed raw data and low speed health data.
- High Security with built-in encryption.
- Built-in support to setup and reconfigure sensor networks.
- Low cost with computer and mobile phones as a driving market force.
- Long battery lifetime by using advanced transmission scheme and decentralized computing.
- Better time synchronization by extending the standard modulation rate recovery.

There are two ways to develop a sensing application using Bluetooth technology. The first way is compliant with Bluetooth specifications. The second way is not compliant with Bluetooth specifications REF [10].

1. Bluetooth specifications compliant Approach

Manufacturers who are implementing Bluetooth technology in their product and marketing it implement this approach. This is an expensive way because it involves Bluetooth Development Kit (BDK), which costs about $40000-$50000 US dollars.

There are several kits available in the market. One of the first being introduced is Ericsson Bluetooth Development Kit (EBDK). The kit is a platform that a developer uses to test out and evaluate the Bluetooth system. It offers developers early stage development of Bluetooth products. The kit is composed of Hardware and Software solutions. The Hardware consists of a motherboard with two additional boards mounted piggyback on the Baseband board and the radio module board. See Figure 13. The motherboard's main task is to support different interfaces, which developers use to easily access the Bluetooth Baseband and radio module.

The Baseband board contains the heart of the system that is an ARM7 thumb processor. The processor implements the Bluetooth Baseband functions using hardware logic together with ARM software located in the flash memory. The processor also implements the HCI layer that is accessible through the motherboard where the interface driver is located.

The radio board consists of two boards, Antenna board and radio module board. The Radio board is mounted above the Baseband board and contains a radio module called PAB313 together with some discrete components that minimize the risk of power output from the module to the antenna.

The software solution used by the kit is a Win32 C++ application with user interface that includes Bluetooth PC reference stack in an executable form. Also included is an application wizard for Host application development and HCI scripting tool. Last, The software also has a packet builder utility, used to display user entered packets detail.

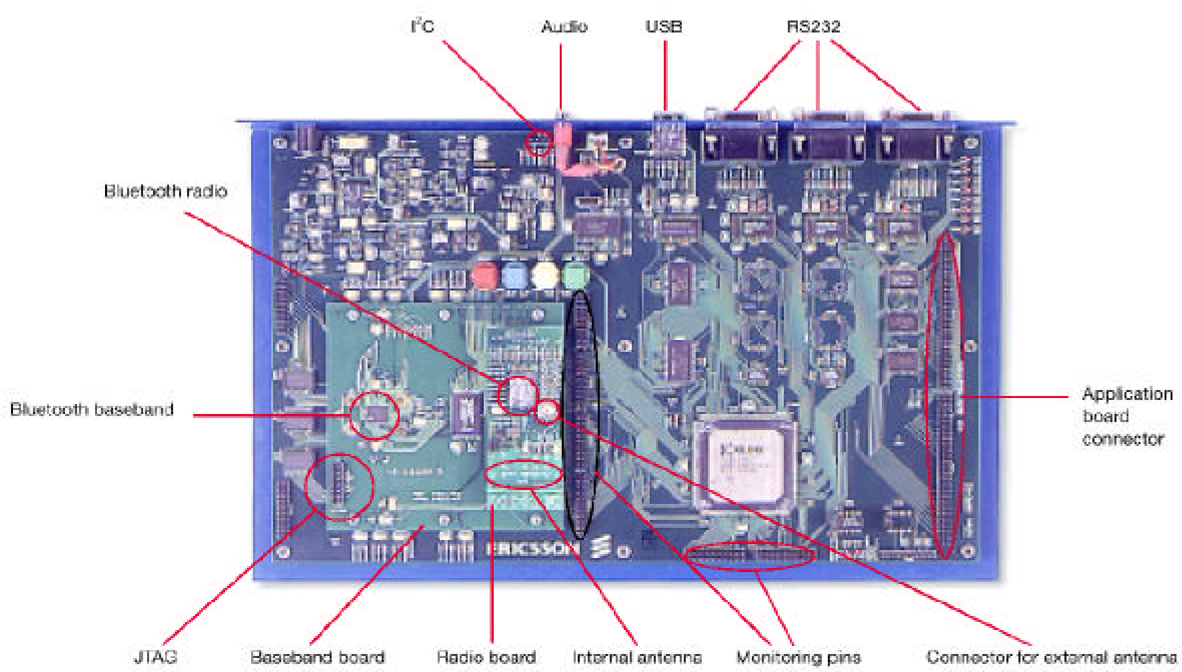

Figure 13. Ericsson Bluetooth Development Kit (EBDK).

2. Bluetooth Specifications noncompliant Approach

The second approach is not compliant with Bluetooth specifications but is much cheaper than the first approach. Researchers and university students having the required background in circuit building and programming coding use this application.

The approach has hardware and software solutions to develop a sensing application with Bluetooth technology support. The hardware solution consists of two boards. The Bluetooth module and antenna board are depicted in Figure 11 along with a special Circuit Board (SCB) built with the components listed in table (5-1).

Bluetooth module board has the lower layer protocols: Radio, Baseband and Link Manager. The Communication between the two boards is done by using one of the physical interfaces mentioned in REF [10] (RS232, UART, USB). Usually RS232 is the simple one to use.

The SCB task is the communication link between the Bluetooth module board and the sensor. The signal received from the sensor, in analog format, is sampled by an analog to digital converter (ADC) and forwarded to the Bluetooth module board. This transmits the data to another Bluetooth module connected to a monitoring station.

A microcontroller handles all the communication to and from the SCB. A microcontroller like PIC16F876 can be used since it has a lot of built-in functionality, such as A/D-converter, Timer, and Flash Memory. This makes both the hardware and the software easier to implement.

The software solution for the SCB can be coded in C++ or Assembly language and then down loaded into the flash memory of the microcontroller using any of the commercially available microcontroller programmers like the one shown in Figure 14. The program should be coded to communicate with the module via a HCI command interface. For design simplicity the software should be coded as the module is in the Slave mode REF [9].

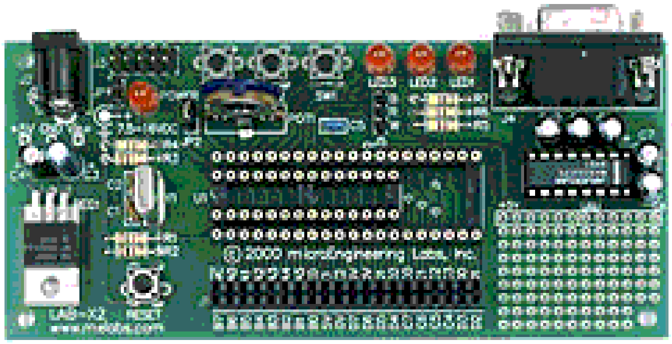

Figure 14. Microcontroller Programmer.

No	Part	Function
1	**Sensor**	Depend on the application.
2	**Bluetooth Module**	Have the lower layer protocol.
3	**Misrocontroller PIC16F876 contains an ADC and memory.**	Digitizing the signal and controlling Bluetooth module.
4	**RS232, Max 203 ECPP**	Transport media between the Microcontroller and the Bluetooth module.
5	**Power supply socket.**	To supply the required power to the boards.
6	**Socket for input.**	To receive signal from sensor.
7	**RS232**	For communication between the SCB and the Bluetooth module.

Table 1. Components needed for building Sensing application with Bluetooth.

VI. BLUETOOTH PRODUCTS AND LABORATORY TESTING

This chapter describes several Bluetooth products available commercially followed by the testing procedure. The main purpose of the testing is to learn how to connect sensors to Bluetooth modules. One of the difficulties faced at the time when this thesis was written was to find a vender who was willing to sell a Bluetooth module, with the lower layer of the protocol.

Because sensors have no profile in the Specifications a new profile has to be created in order to provide produced data recognized by other Bluetooth units. Making this profile requires a development kit, which is too expensive to be used for research and educational purposes.

Selected products available on the market were acquired for testing in the lab. Specifically, the products listed in Table (2) were purchased. The purpose of the testing was to comparatively evaluate some of the commercial Bluetooth wireless products. The goal of the testing was to evaluate the Bluetooth module in each of these products by sending wireless data using a Bluetooth module to the receiving end, comparing the transmitted and received data.

No	Product Name	Manufacturer	Function
1	LMX3162 Evaluation Board.	National Semiconductor, Inc.	Evaluation of the LMX3162 single chip radio transceiver.
2	Bluetooth PCMCIA adapter.	Xircom	File transfer and synchronization services.
3	Cross Net CN1000LX node.	Crossbow Technology	4 channels input as sensors Bluetooth transceiver.
4	Cross Net BT100	Crossbow Technology	Bluetooth transceiver and serial communication with PC.

Table 2. Bluetooth Products.

A. LMX3162 EVALUATION BOARD KIT

This kit was the first product brought to the lab. Even though this kit has a Bluetooth capability, its main purpose is to evaluate the LMX3162 single chip radio transceiver on the board, which is not the main goal of this thesis.

The LMX3162 Evaluation Kit consists of the LMX3162 Evaluation Board, Code Loader software, and Microwire emulation cable. The board enables all performance measurements with no additional support circuitry.

The board consists of the LMX3162, a modular RF VCO, a ceramic RF filter, a discrete LNA, and an IF SAW filter. The Emulation cable connects the evaluation board to the parallel port of a PC, facilitating the emulation of a Microwire Bus connection between the PC and the evaluation board. The Code Loader software does the emulation. See Figure 15.

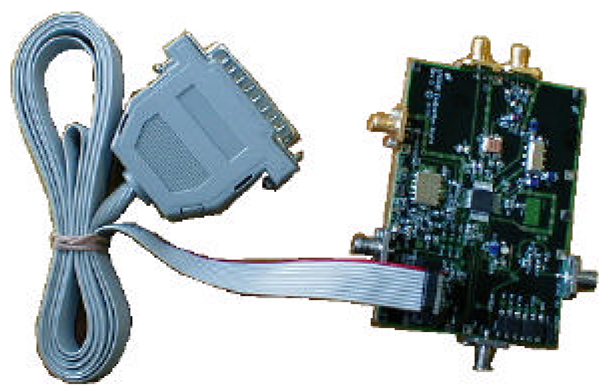

Figure 15. LMX3162 Evaluation Board Kit.

B. XIRCOM BLUETOOTH PCMCIA ADAPTER

This Bluetooth adapter has the core protocols built into it, while the higher layer protocols are installed by the software in the computer. Adapter includes two services: synchronization, and file transfer. The product was tested and recognized by another Bluetooth card installed in a remote notebook computer.

Figure 16. XIRCOM Bluetooth PCMCIA Adapter.

C. CROSSNET KT100

The CrossNet KT100 is the main product for testing as it is manufactured to test sensors with Bluetooth module. This product has two parts, CN1000LX and BT100. See Figure 17. The CN1000LX has a Bluetooth module and stack programmed into a micro controller, which accepts four input channels. Each channel is designed to be connected to a different sensor, which supplies an analog signal to the multiplexor. The multiplexor feeds the signal to an ADC built in the product and then to the Bluetooth module. The signal is then passed through the lower protocol layers while transmitting the data via an antenna to the BT100.

The BT100, having the other Bluetooth module, is connected to a Pentium computer via a serial communication port. The rest of the higher layer protocols of the stack are installed by software with an accompanying CD. The software enables communication between BT100 and the computer.

Figure 17. CROSSNET KT100

Product application is designed to receive the data and does not have similar services like other Bluetooth products. The application interface is shown in Figure 18.

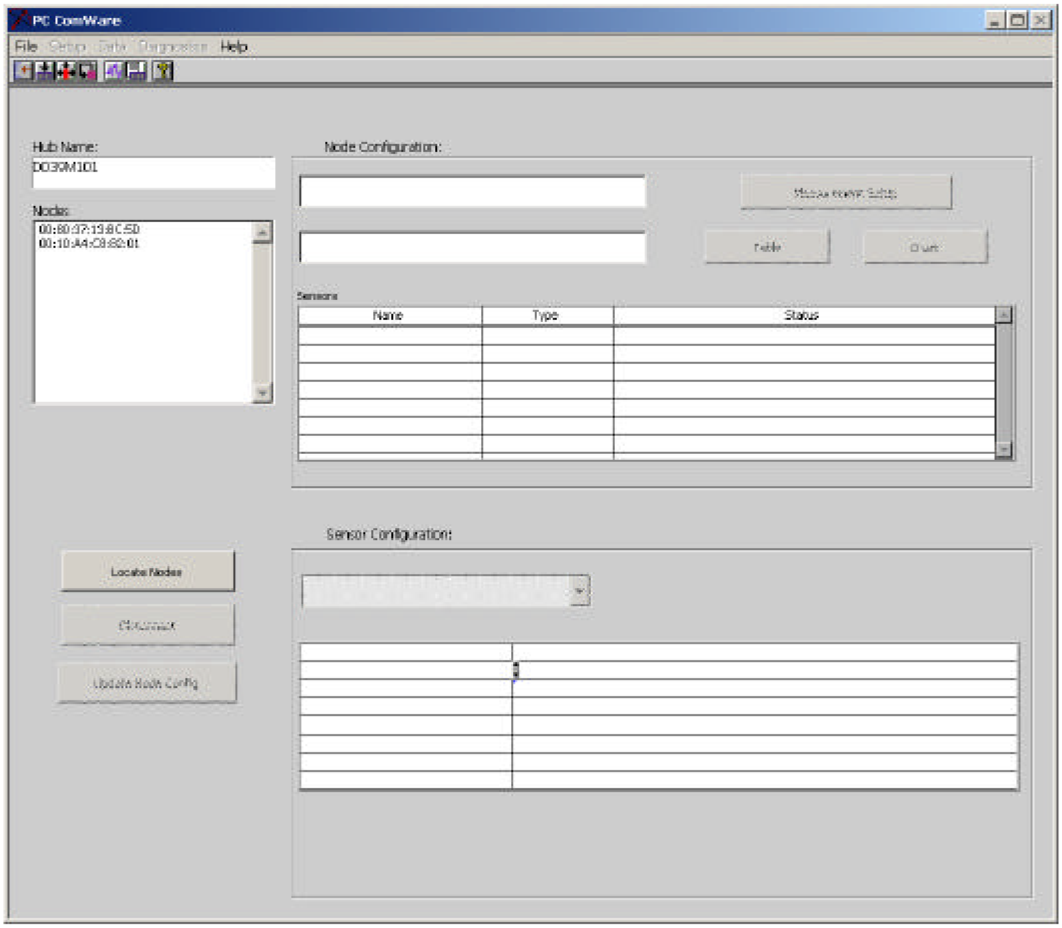

Figure 18. CROSSNET KT100 Application Interface.

D. TESTING PROCEDURE

The testing procedure was carried out in two phases. The goal of first phase was to test whether Bluetooth units recognized each other in a piconet. The CN1000 was connected to the WAVETEK function generator acting as a sensor. The BT100 was connected to a desktop Pentium computer. Xircom PCMCIA was plugged into a Sony notebook and the required software installed. After running the application on the desktop computer the BT100 identified two Bluetooth devices and displayed their MAC addresses. See Figure 19. The application was able to access CN1000 since it is designed for this purpose; however, it could not access the PCMCIA card, which have different services.

The goal of the second phase was to evaluate the transmitted signal to the received one by connecting the CN1000LX to the function generator acting as a sensor and the BT100 to a desktop computer. After this the received signal was evaluated and compared to the transmitted one.

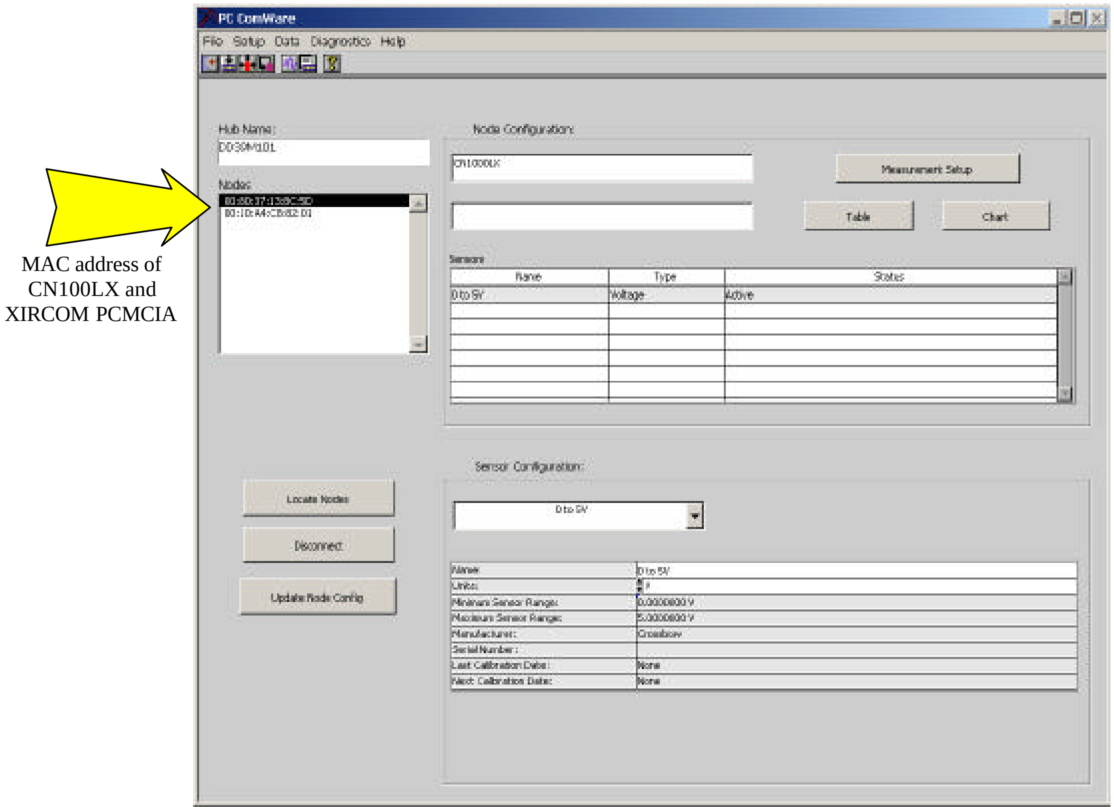

Figure 19. Application Interface recognizing other Bluetooth units.

The test was conducted again but this time with two function generators acting as sensors to the CN100LX unit. See Figure 20. Both signals, which are depicted in Figure 21, were received and evaluated.

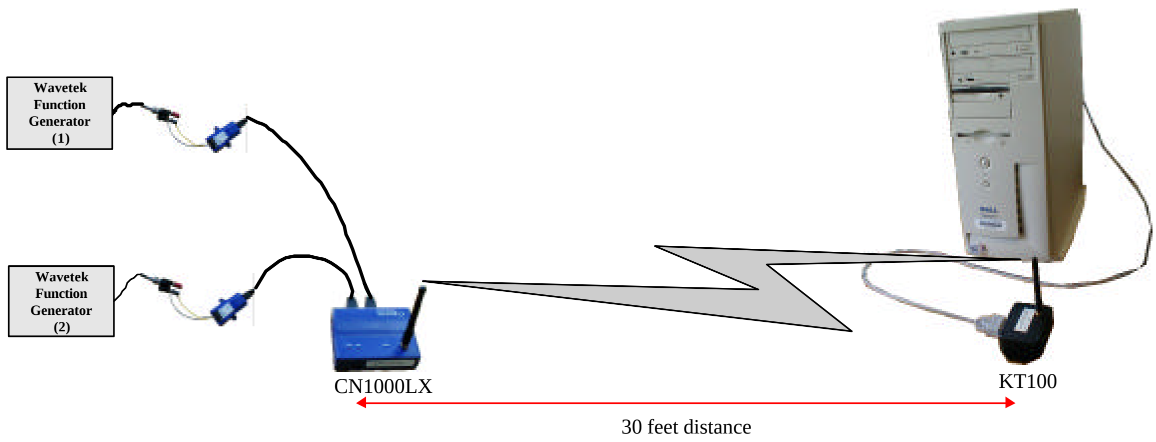

Figure 20. Connecting CN1000LX.

Next, the unit was fed with two different waveform signals each with different frequency. The first signal was a rectangular waveform with 2 Hz and 10 mV. The second signal was a sine wave with 3 Hz and 20 mV. Figure 21 shows the result of this test. Finally, the frequency for the sine waveform was increased and the effect was instant and visible. See Figure 22.

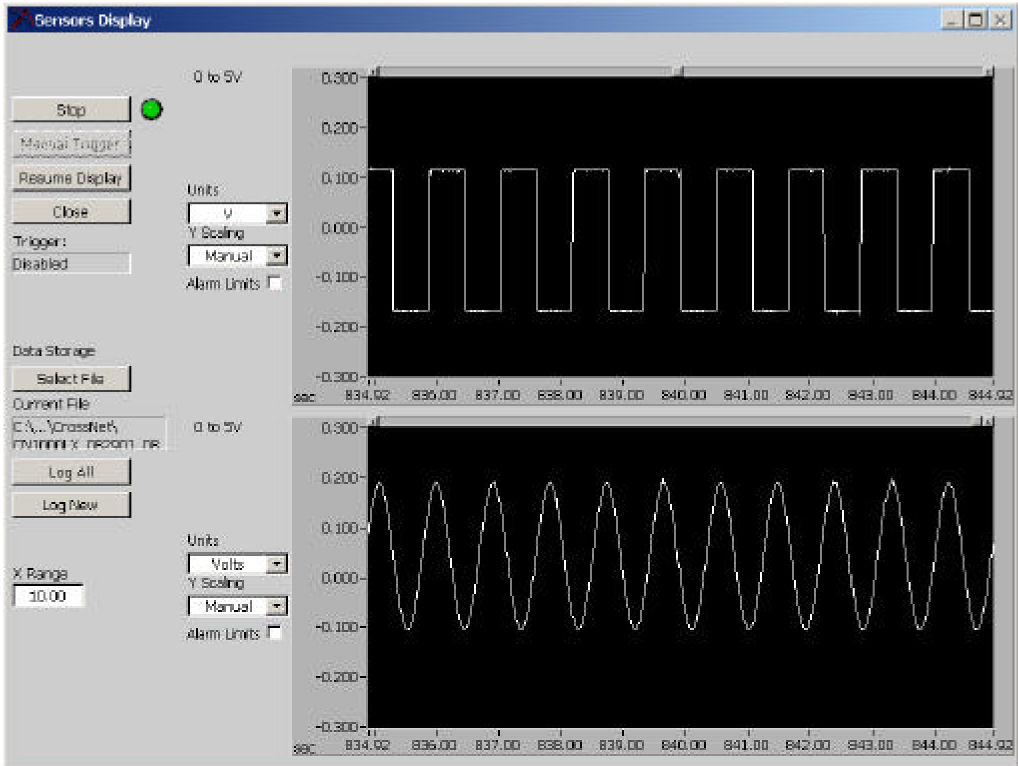

Figure 21. Signal reception from CN1000LX.

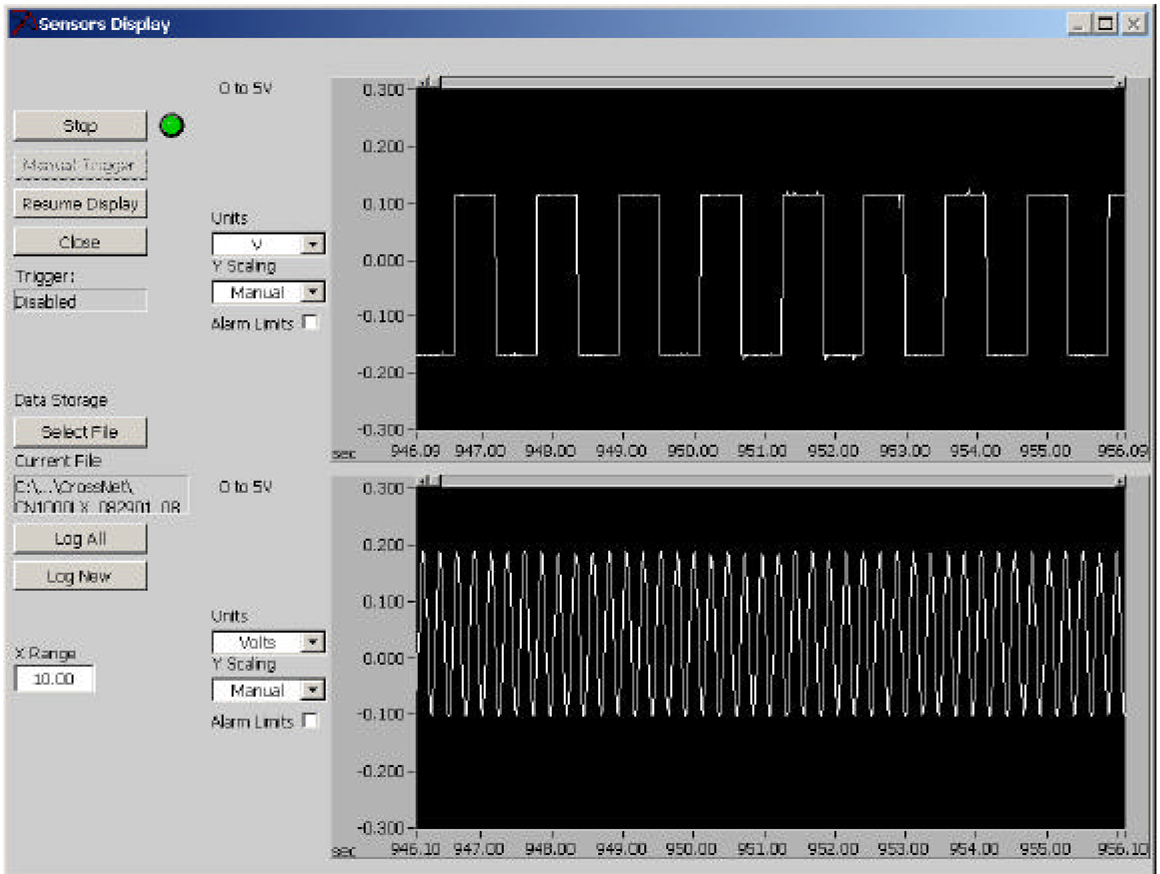

Figure 22. Signal Frequency change measurement.

VII. CONCLUSION AND RECOMMENDATION

A. CONCLUSION

Today sensors and gauges are used for different purposes in various civilian and military applications. One particular military application is onboard ships and submarines where these sensors and gauges are connected via wires to the monitoring stations. Using wireless LANs to connect these sensors and gauges would eliminate wires. Although the market carries many wireless LANs to accommodate this military application, what is needed is a technology that implements small devices, consumes less power and provides an ad hoc networking ability.

One such technology is Bluetooth, which is rapidly growing in various applications. Products implementing this technology are continuously increasing in the market. The main purpose of this technology is to eliminate cable by using radio frequency transceivers consuming less power and money. Bluetooth has open Specifications helping venders to design products that interact with each other. The technology serves both voice and data simultaneously connecting units within 30 feet. This distance is extendable to 300 feet in order to accommodate the dimensions of ships and submarines.

Bluetooth technology using Frequency Hopping techniques reduces the probability of interference between the units. Up to seven units implementing this technology can be linked and controlled by one Master in a new network concept called Piconet, which are then linked to a Scatternet. This technology also uses radio frequency providing it the ability of transmitting data in all directions to penetrate obstacles. The Specifications define the protocol stack into four layers according to their purpose, including the occurrence of Bluetooth SIG specifying these protocols. Additionally, the Specifications define profiles for usage models without any profile, specifically for sensor and gauge applications.

The integration of Bluetooth technology and sensors would greatly improve the efficiency and the accuracy of a number of float tasks. In the next few years, I believe, the Specification profiles will be customized for sensors. For the time being, connecting this technology to sensors or gauges requires a Bluetooth Development Kit, which is used by developers to build and evaluate any application implementing Bluetooth. Although many attempts at connecting Bluetooth to sensors have been tested by various researchers and university students, See [REF 9], the resulting products are not compliant with Bluetooth Specifications. Nonetheless required hardware to integrate this technology is available and inexpensive. Furthermore the required software can be coded according to the required application.

Adequate information is presently available for integrating a sensor with Bluetooth module; however, the process needs further development. Therefore, this thesis is devoted to analyze Bluetooth technology and searching for the most efficient means of connecting the sensors to such technology.

B. RECOMMENDATIONS

Due to the growing demands of Wireless LANs and the advantages that Bluetooth technology offers, the number of military applications for this technology is enormous. Most importantly, this technology provides a wireless and mobile environment for ships and submarines.

In order to simplify the task of building a sensor application using Bluetooth, It is recommended to follow the method explained in [REF 9]. This recommendation is based on simplicity, availability and success of the method and components used. Finally, for a further thesis topic, It is further recommended to monitor and analyze the effect and interference of using both Bluetooth and an IEEE 802.11 that operate in the same area.

LIST OF ACRONYMS

Acronym	Meaning
ACL	Asynchronous Connectionless.
AP	Access Point.
API	Application Program Interface.
ATM	Asynchronous Transfer Mode.
BDK	Bluetooth Development Kit.
BSS	Basic Service Set.
CSMA/CA	Carrier Sense Multiple Access with Collisio n Avoidance.
DECT	Digital Cordless Telecommunications Standard
DS	Distribution System.
DSL	Digital Subscriber Line.
EBDK	Ericsson Bluetooth Development Kit.
ESS	Extended Service Set.
ETSI	European Telecommunications Standards Institute.
FCC	Federal Communication Commission.
FEC	Forward Error Correction
FSK	Frequency Shift Keying.
GAP	Generic Access Profile.
GOEP	Generic Object Exchange Profile.
HCI	Host Controller Interface.
HTTP	HyperText Transfer Protocol.
IBSS	Independent Basic Service Set.

IEEE	Institute for Electrical and Electronic Engineers.
IM	Inter Modulation.
IP	Internet Protocol.
IR	Infra Red.
IrDA	Infrared Data Association.
ISM	Industrial Scientific and Medicine bands.
ITU	International Telecommunication Union.
L2CAP	Logical Link Control and Adaptation Protocol.
LC	Logical Control.
LMP	Link Manager Protocol.
MAC	Media Access Layer.
OBEX	Object Exchange Protocol.
OFDM	Orthogonal Frequency Division Multiplexing.
OSI	Open System Interconnection.
PAN	Personal (Private) Area Network.
PC	Personal Computer.
PDA	Personal Digital Assistant.
PIN	Personal Identification Number
RF	Radio Frequency.
SCO	Synchronous Connection-Oriented.
SDAP	Service Discovery Application Profile.
SDP	Service Discovery Protocol.
SIG	Special Interest Group.

TCP	Transport Control Protocol.
TCS	Telephony Control Specification.
TDMA	Time Division Multiple Access.
UART	Universal Asynchronous Receiver-Transmitter
UDP	User Datagram Protocol.
USB	Universal Serial Bus
WAP	Wireless Application Protocol.
WEP	Wired Equivalent Privacy.
Wireless LAN	Wireless Local Area Network.

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5. Dr. Wolfgang Baer
   Naval Post Graduate School
   Monterey, CA 93943-5101
   baer@cs.nps.navy.mil

6. Lt.Cdr Ali M Aljuaied
   Naval Post Graduate School
   Monterey, CA 93943-5101
   amaljuar@nps.navy.mil